Strangelets in cosmic rays

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Recently new data from the Cosmo-LEP project appeared, this time from DELPHI detector. They essentially confirm the findings reported some time ago by ALEPH, namely the appearence of bundles of muons with unexpectedly high multiplicities, which so far cannot be accounted by present day models. We argue, using arguments presented by us some time ago, that this phenomenon could be regarded as one more candidate for the presence in the flux of cosmic rays entering the Earth's atmosphere from outer space nuggets od Strange Quark Matter (SQM) in form of so called *strangelets*.

1. INTRODUCTION

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It is worth to remind here that CosmoLEP data are very important because: (a) the high multiplicity cosmic muon events (*muon bundles*) are potentially very important source of information about the composition of primary CR because muons transport in essentially undisturbed way information on the first interaction of the cosmic ray particle with atmosphere; (b) such events have never been studied with such precise detectors as provided by LEP program at CERN, nor have they been studies at such depth as at CERN [7] (ranging between 30 and 140 meters what corresponds to muon momentum cut-off between 15 and 70 GeV).

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2. SOME FEATURES OF STRANGELETS

For completeness let us remind here the most important for us features of strangelets (see [3,4] for details). They are hadron-like being a bag of up, down and strange quarks (essentially in equal proportion) becoming absolutely stable at high mass number A (more stable than the most tightly bound nucleus as iron). However, they become unstable below some critical mass number, $A_{crit} = 300 - 400$. Despite the fact that their geometrical radii are comparable to those of ordinary nuclei of the corresponding mass number A, $R = r_0 A^{1/3}$, they can still propagate very deep into atmosphere. This is because [3] after each collision with the atmosphere nucleus strangelet of mass number A_0 becomes just a new

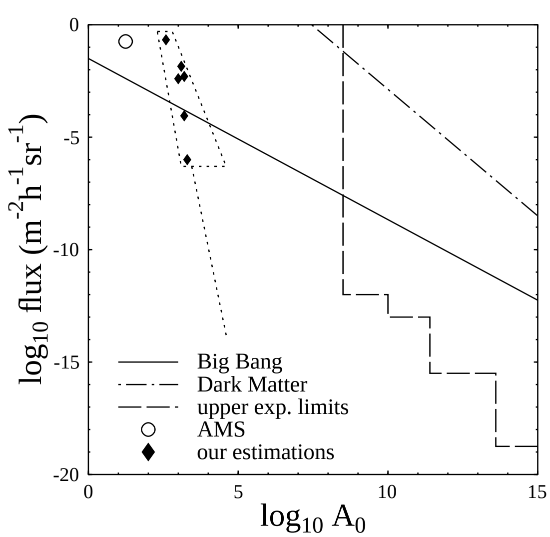

Figure 1. The estimated flux of strangelets [4] compared with existing upper experimental limits [9] and with other predicted astrophysical limits.

strangelet with mass number approximately equal $A_0 - A_{air}$ and this procedure continues unless either strangelet reaches Earth or (most probably) disintegrates at some depth h of atmosphere reaching $A(h) = A_{crit}$. Actually, in a first approximation (in which $A_{air} << A_{crit} < A_0$), in the total penetration depth of the order of

$$\Lambda \simeq \frac{4}{3}\lambda_{N-air}\left(\frac{A_0}{A_{air}}\right)^{1/3} \tag{1}$$

where λ_{N-air} is the usual mean free path of the nucleon in the atmosphere.

There are number of candidates for strangelets known in the literature, the common feature is their small ratio of charge Z and mass A numbers, Z/A. The so called *Saito events* have $Z \simeq 14$ and $A \simeq 350$ and $A \simeq 450$ [8]. The most spectacular is *Price event* [9] with $Z \simeq 46$ but $A > 1000$. On the other hand the *Exotic Track event* (ET) [10] has been produced after the respective projectile has traversed ~ 200 g/cm^2 of atmoshere. Finally, the so called *Centauro events* [11] has been produced at depth ~ 600 g/cm^2 and contains probably ~ 200 baryons [12]. In Fig. 1 we show the resulting flux of strangelets obtained by considering the above signals [4]. One can add to them the recently registered with AMS detector [13] event with small ratio Z/A and also very small A, estimated to be $A \simeq 17.5$, it could be a metastable strangelet.

3. RESULTS

This is the picture we shall use to estimate the production of muon bundles produced as result of interaction of strangelets with atmospheric nuclei. We use for this purpose the SHOWERSIM [14] modular software system specifically modified for our present purpose. Monte Carlo program describes the interaction of the primary particles at the top of atmosphere and follows the resulting electromagnetic and hadronic cascades through the atmosphere down to the observation level. Registered are muons with momenta exceeding 70 GeV for ALEPH and 50 GeV for DELPHI. Primaries initiated showers were sampled from the usual power spectrum $P(E) \propto E^{-\gamma}$ with the slope index equal to $\gamma = 2.7$ and with energies above $10 \cdot A$ TeV.

The integral multiplicity distribution of muons from ALEPH data are compared with our simulations in Fig. 2. For completeness DELPHI data are present also. At first we have used here the so called "normal" chemical composition of pri-

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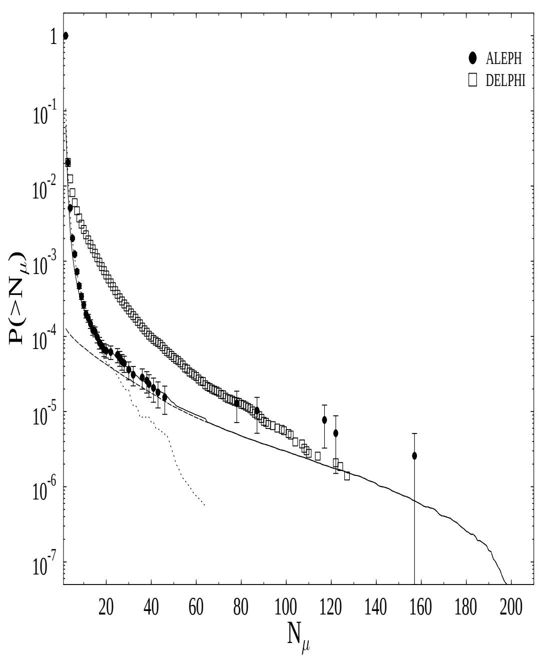

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4. CONCLUSIONS

To conclude: we propose to regard the Cosmo-LEP data on CR muons obtained so far as an additional possible signal of the possible SQM admixture present in the primary CR flux. We would like to add here that such admixture would also contribute to CR flux at energies greater than GZK cut-off [4,16] explaining therefore this phenomenon in a quite natural way[6]. This makes strangelets interesting subject to investigate in the future.

We would like to close with the following remark. With the flux of strangelets as estimated by us and used here (equal to $F_S/F_{total} = 2.4 \cdot 10^{-5}$ in the enrgy range of tens of GeV) the energetic spectrum of strangelets should fall like $\sim E^{-2.4}$, i.e., with spectral index being much smaller than for protons. Actually, this result agrees nicely with A-dependence of the spectral index of CR's obtaine when fitting the world CR data [18].

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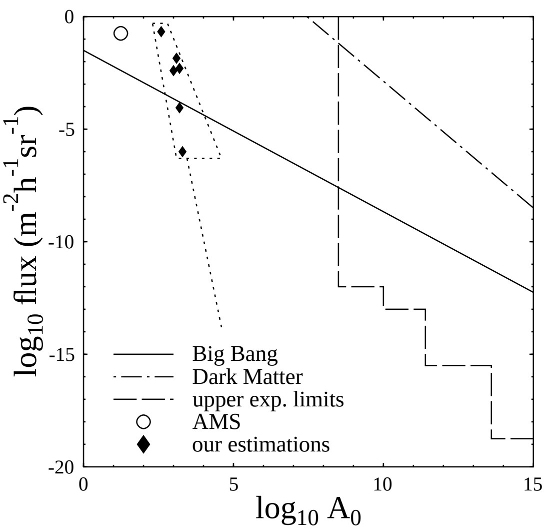

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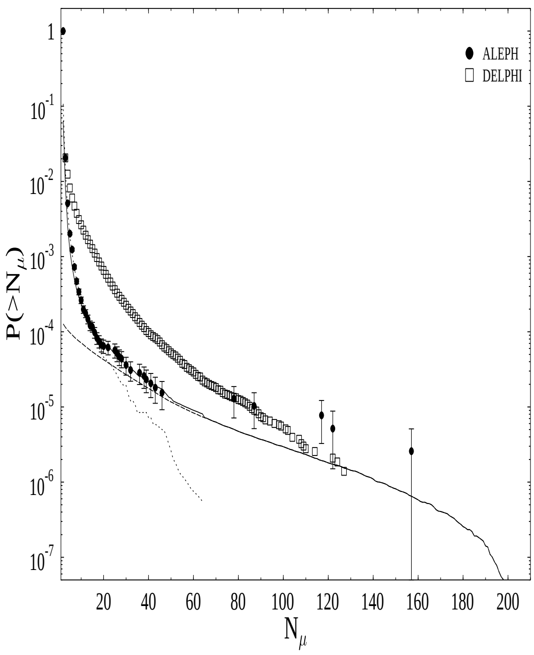

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